What is ASTROBIOLOGY

Astrobiology is the scientific study of the origin, evolution, distribution, and future of life in the universe. The study of astrobiology brings together researchers from historically separate scientific fields such as microbiology, ecology, astronomy, geology, paleontology, and chemistry and encourages them to work together to answer the most fundamental questions science can pose: What is life? How did we get here? Are we alone in the universe? How can we tell if we are?

These questions have been asked for generations, but it is only recently that we have had the technology and the knowledge to address them from a scientific perspective. Understanding the answers requires that researchers develop a larger perspective than is possible within any one field of science. Astrobiology is a collaborative effort, transcending traditional scientific discipline boundaries.

Researchers begin by studying life on Earth, the only place in the universe where we know life exists. How did life begin here? How has it responded to changes in the environment? How has it changed the environment? What conditions does Earthly life need to exist? The scientists of the NASA Astrobiology Institute, among others, seek to answer these questions and many more.

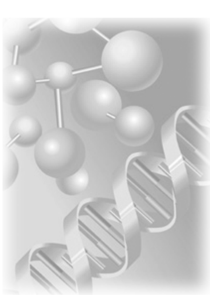
The next step is to look beyond Earth to the possibilities of life elsewhere. Most of life on the Earth is microbial, and it's likely that microorganisms will be the type of life we will find elsewhere in the universe. Astrobiology researchers try to figure out how to search for microbes and other life on the planets and moons in our Solar System and on Earth-like planets orbiting other stars. How do you detect evidence of biology when you can't hold a soil sample in your hand? Does life leave its mark on a planet so that we can detect its presence remotely? Is life common? Or is our life-filled Earth rare and unique?

What is life? Where does life exist?

The following background information supports Activities I and II

Astrobiologists also struggle with the question: what exactly does it mean to be alive? Life as we know it here on Earth exchanges energy with the environment. It grows, develops, and reproduces, storing genetic information in DNA and RNA and passing it from one generation to the next. Life is composed of one or more cells. It produces waste products. Life evolves, adapting to changes in the environment and changing the environment in return. Life is based on the chemistry of carbon and requires liquid water.

The "liquid" part is important. It's very hard to transport important substances, like nutrients or metabolites, from one place to another within a solid, and it's hard to control that transport in a gas. Liquids can do it well.



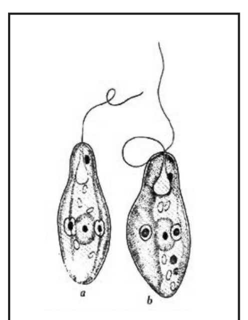
Water has many qualities that make it an ideal medium for the cellular biochemical reactions necessary for life. Through an intricate chemistry, water molecules help the molecules of life, such as DNA, enzymes (proteins that speed up chemical reactions), and sugars such as glucose (a common sugar used for energy), orient themselves in the proper three-dimensional shape needed to carry out their functions in the cell. In order to maintain osmotic balance (and avoid shriveling or bursting), cells also need to transport dissolved solutes such as calcium and potassium ions across the membrane. Water provides the medium for dissolution, and as a fluid provides a means of transporting molecules in, around, and out of the cell.

Water is the only chemical compound that is found naturally on Earth in all three physical states – gas, liquid, and solid. This fact allows the water cycle of evaporation, condensation, and precipitation between reservoirs in the oceans, on land, and in the air to exist. Indeed, water is one of the few substances that can be liquid at the temperatures and pressures typical of the Earth's surface (mercury and liquid ammonia are the others). Water will remain liquid over an extremely large range of temperatures, freezing at 0°C (32°F) and boiling at 100°C (212°F). Adding salt will lower the freezing temperature, and adding pressure can raise the boiling point, increasing the range even more. Plus, it takes a lot of energy to raise the temperature of water a few degrees. All of which means that temperatures on Earth can undergo rather large variations without liquid water freezing or boiling away.

In another sense, much of life on Earth depends on the water molecule for survival. Many microorganisms and plants carry out photosynthesis, the biochemical process of creating sugars from CO_2 in the air and energy from the sun. Those same microorganisms and plants can then consume the sugars they create, converting them to usable energy needed for growth and reproduction. Many other organisms, such as humans, then consume the plants as food. The reactions of photosynthesis split apart a water molecule and use its electrons to build one large six-carbon sugar molecule from six small one-carbon CO_2 molecules.

Life in extreme environments

On Earth, life is found anywhere liquid water is present. It has only been in the past few decades that scientists have realized "anywhere" includes such extreme environments as ice-covered Antarctic lakes, hydrothermal vents on the ocean floor, and deep subsurface rocks. The organisms that live in these harsh conditions are called extremophiles. Most are bacteria or archaea: microorganisms or microbes, whose DNA is not stored in a central compartment or nucleus. They survive and sometimes thrive in environments once thought too hot, too cold, too salty, too alkaline, too high pressure, too dry, or with too much radiation for life to exist.



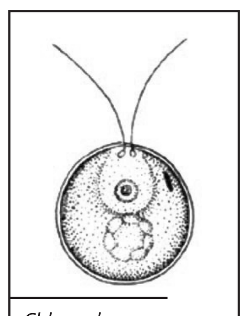
This eukaryotic ciliate survives in boiling water

For example, scientists have long known that microbial mats (large colonies of microbes) are responsible for the beautiful colors observed in Yellowstone National Park's many hot springs. The water in these springs tops 90°C (188°F), much too hot to touch. Some hot springs are also extremely acidic, with pH levels, in a few cases, similar to that of stomach acid. Yet life thrives in and around them.

In 1977, scientists were stunned to discover abundant life clustered around hydrothermal vents on the ocean floor thousands of feet below its surface. The vents form where the Earth's crustal plates crack and spread apart. Molten rock, or magma, wells up along these cracks, forming long mountain ranges known as mid-ocean ridges. Seawater seeps deep into the rock at the cracks, is heated and shoots back upward through a vent, enriched with minerals leached from the rocks along the way. Scientists had thought life would be impossible in the scorchingly hot temperatures (400°C, 750°F), oppressively high pressures (thousands of pounds per square inch), complete darkness, and toxic chemical brew typical of the area around these ocean-floor vents. But the high pressure keeps the hot water from boiling. And, in place of sunlight, bacteria living there use chemical reactions involving hydrogen sulfide, common in the enriched seawater pouring out of the vent, to generate energy. Other creatures survive there by eating the bacteria, or each other. Should the flow of hot, enriched water slow to a trickle for any reason, the creatures around it would soon die.

Lifeforms discovered at the vents include mussels, clams, shrimp with no eyes, and giant tube worms that can reach ten feet in length. The tubeworms have no stomachs or mouths. They depend on symbiotic bacteria in their guts for their nutrition, a relationship that benefits both the worm and the bacteria. Hemoglobin in the worm's red tips grabs hydrogen sulfide from the water around the vent and transports it to the bacteria living inside the worm. Using this hydrogen sulfide as an energy source, the bacteria, in turn, convert carbon dioxide dissolved in the water into carbon compounds that nourish the worm.

Researchers have also found bacteria in small pockets of liquid water embedded six feet deep in "solid" ice in the McMurdo Dry Valleys of Antarctica. These valleys are among the coldest, driest places on Earth, with average temperatures of -20°C (-4°F) and less than 10 centimeters (four inches) of precipitation a year. Small amounts of dirt contained within the ice retain heat from the Sun, melting small amounts of ice in the area directly surrounding them. The dirt also provides chemical nutrients for the bacteria that photosynthesize, grow, and reproduce in the water pockets during the long Antarctic summer days.



Chlamydomonas live in pockets of liquid water six feet deep in "solid" ice.

The Rio Tinto river in southwestern Spain is another interesting environment for life. It is highly acidic, with a pH of 2.3 in most of the river (only slightly less acidic than sulfuric acid). The high acidity results from chemical reactions between the water and iron and sulfur minerals in the rocks around the river. The river has a deep red color, like red wine, because of iron dissolved in the water. Microbes living in the water use chemical reactions with iron and sulfur minerals to generate energy. Metabolic products from these reactions also contribute to the low pH of the river. Numerous algae and fungi also thrive here.

Perhaps most surprising, scientists have discovered bacteria living in rock buried 1.5 kilometers (nearly a mile) underground in an area known as the Columbia River Basalts in the state of Washington. The bacteria survive in small holes and cracks in the rock that fill with water from underground aquifers. They live in complete darkness, at temperatures that approach 40°C (100°F) because of heat generated in the Earth's core. The groundwater reacts chemically with minerals like olivine and pyroxene in the rock to create hydrogen. The bacteria use this hydrogen, and dissolved carbon dioxide, to make the methane and other hydrocarbons they use to survive. In essence, the bacteria live on nothing but the rock and water. The scientists who discovered the bacteria refer to them as "SLiME" for Subsurface Lithoautotrophic Microbial Ecosystem (autotroph refers to bacteria that make organic carbon molecules from carbon dioxide. The word (litho) refers to rocks.) Indeed, scientists have calculated that the weight of all the microbes that live underground equals that of all organisms that live above the surface (non-microbes, like humans, included).

"Extreme" vs. "Normal"

Of course, to the extremophiles described above, the conditions in which they live are "normal." To them, the conditions we traditionally associate with life (moderate temperatures, sea level pressures, plenty of sunlight, an oxygen-rich atmosphere) are "extreme" and deadly. "Normal" and "extreme" are relative.

Interestingly, conditions that we think of as "extreme" on Earth may be similar to what is "normal" elsewhere in the solar system. Understanding how life survives in Earthly extreme environments can help scientists better understand how life might exist on other planets and moons.

One thing extremophiles have in common with the rest of us is that they too require liquid water to survive. Consequently, when scientists think about non-Earthly places where life may exist, they look for sites where liquid water either is now or was once at some time in the past.

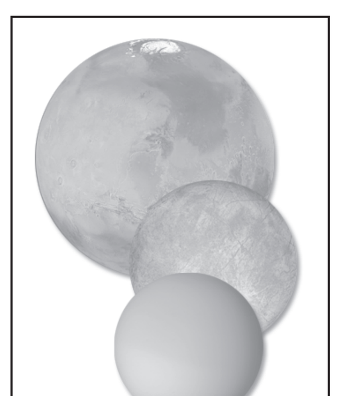
Life on Mars?

Mars today is a frozen, bone-dry world. Its predominantly carbon-dioxide atmosphere is too thin to support liquid water on its surface, even if Mars' surface temperatures could somehow be raised above their average of -65°C (-85°F). Yet its surface is covered with winding channels that resemble dry riverbeds, and there is plenty of water ice frozen in the planet's polar ice caps and permafrost. Enormous volcanoes indicate Mars was once tectonically active, even if its core is now too cold to support volcanic activity. All of this indicates Mars might have once had a thicker, warmer atmosphere, and that means liquid water might once have flowed on its surface. Could life have developed then and somehow found a way to survive the shift from moderate to extreme conditions? The frozen deserts of Antarctica resemble the Mars of today. If life can persist deep in the ice and underground rocks on Earth, perhaps it survives in the permafrost or polar ice caps of Mars.

An ocean on Europa?

Europa, a moon of Jupiter which is slightly smaller than Earth's Moon, is one of the smoothest objects in the solar system. It is thought that a liquid water ocean between 50 and 100 kilometers deep covers its rocky interior, which in turn is covered by a layer of frozen water ice a few kilometers thick. Few impact craters (formed by collisions with large meteorites) mar this moon's icy crust, indicating Europa's surface may be only a few million years old (the older a surface, the more time meteorites have had to strike it and the more impact craters that should be visible). Instead, cracks and light and dark streaks crisscross Europa's surface. Europa is pulled into a slightly elongated shape by Jupiter's strong gravitational pull, in much the same way the Moon's smaller gravitational pull causes tides on the Earth. But Europa also feels a gravitational pull from each of Jupiter's other large moons, and the combination of all these conflicting tugs causes Europa to twist and flex ever so slightly as it orbits Jupiter. Over time, this tidal flexing has heated Europa's interior, in much the same way that repeated bending heats a wire hanger. This heat may have melted the ice, creating an immense ocean of liquid water perhaps a hundred kilometers deep underneath Europa's thin icy shell. Scientists think some of this water seeps up through cracks in the ice caused by the gravitational twisting of the ice sheet, creating the streaks observed on the surface.

A curious analog to Europa's ice-covered ocean can be found in Antarctica. In 1996, scientists discovered evidence of a lake of liquid water deep underneath the ice at Russia's Vostok Station about 1,000 kilometers (1,600 miles) from the South Pole. Dubbed Lake Vostok, the liquid water sits under about 3,710 meters (12,169 feet) of ice and may be 500,000 to a million years old. Lake Vostok, about the size of Lake Ontario, is thought to be about 484 meters (1,600 feet) deep, with about 50 meters (165 feet) of sediment at its bottom. No one knows if there is any kind of life in Lake Vostok. So far, scientists have not drilled into the lake's water, for fear that organisms carried by the drilling equipment will somehow contaminate the lake. Contamination by Earthly organisms is a concern for researchers who want to look for evidence of life in Europa's ocean too. The techniques that scientists develop to drill without contamination into Lake Vostok will prove invaluable if landers and drills are ever sent to Europa to search for evidence of life there.



Mars, Europa, Titan

Titan's thick atmosphere

Titan, Saturn's biggest moon, is the only moon in the solar system with a thick atmosphere. Multiple layers of clouds and haze completely hide the moon's surface. Methane clouds float close to the surface. A thick smog of organic molecules, about 300 kilometers (186 miles) above the ground, and a thin haze high in the outer atmosphere complete the picture. These clouds and haze keep nearly all sunlight from reaching Titan's surface, which remains at -180°C (-290°F). While too cold for liquid water, scientists have speculated that Titan may have lakes or oceans of liquid hydrocarbons like methane and ethane, a constituent of natural gas here on Earth. Large rocky landmasses, rather like continents, may rise out of the "oceans" on Titan's surface. Conditions on Titan may resemble those on Earth when life first began, which is one reason astrobiologists find this moon of Saturn so intriguing. If all goes as planned, NASA's Cassini mission will insert into Saturn's orbit in July of 2004, and then deploy the Huygens probe to Titan in January 2005. Huygens will enter the murky atmosphere of Titan, and eventually descend via parachute onto its mysterious surface.

Impact of extremophiles

The extreme environments of Mars, Europa, and Titan may or may not harbor life. We do not yet know. Fortunately, scientists can use Earthly extreme environments to test equipment and techniques they may someday use to search for life on these and other planets and moons. For example, scientists have drilled into the rocks under Spain's Rio Tinto River, looking for extremophiles. Subsurface conditions here may resemble those on Mars, where underground liquid water could exist amid rocks rich in sulfur and iron. Experience with the drilling machines used at Rio Tinto will give important insight into the design of drilling machines that could be sent to Mars in the future.

Earthly extremophiles have forever changed our view of life and the conditions life needs to survive. Their very existence has proven to researchers that life can exist in a much broader range of environments. They have forced scientists to expand their ideas of where in space to look for life. It is no longer enough to know only about biology when looking for life. You also have to understand geology, ecology, and chemistry, and the interplay between them all. Astrobiology provides the umbrella under which scientists trained in these different fields collaborate to understand life here on Earth as well as the possibilities of life elsewhere in the universe.

For more detailed background information on astrobiology, including a discussion of the origins of life on the young Earth, the Viking missions to Mars and the search for life there, and other missions to Mars, please go to **http://nai.arc.nasa.gov/poster**.

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How to use this poster in your classroom

http://nai.arc.nasa.gov/poster

- The front of this poster illustrates in words and pictures the fundamental questions addressed by astrobiology: What is life? Where is it? How do you find it?
- Three activities have been developed to explore these themes:
  - Activity I (in its entirety) is on the back of the poster
  - Activities II and III can be found on the website above
- The back of this poster also contains a science background narrative to support the activities, with additional background for Activity III on the website.
- All materials can be found on the website for easy downloading.

For more information about astrobiology, we recommend the following websites. They include additional astrobiology curriculum materials.

The NASA Astrobiology Institute
http://nai.arc.nasa.gov

The SETI Institute
http://seti.org/epo/

Micro*scope
http://microscope.mbl.edu

Content adapted from "Life in the Universe Teaching Guides," copyright: SETI Institute.

http://nai.arc.nasa.gov/poster

Activity 1
Life: What is it? Where is it?

Learning Objectives:
Students will be able to:
- Explain the characteristics of living things and the conditions needed for life.
- Use logic and evidence to explain why the study of extreme environments on Earth is important to the search for life on other planets.

Standards Addressed:
As a result of this activity, students should develop the following understandings about scientific inquiry:
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

Student Prerequisites
Before beginning this activity, students should have a basic knowledge of how life is defined – life grows or evolves in response to changes in the environment, consumes raw materials for energy, produces waste products, and reproduces.

Student Misconceptions
Students may think "life" means intelligent, human-like life and/or familiar forms of life such as plants and animals. According to Benchmarks for Science Literacy (p. 341): Elementary- and middle-school students typically use criteria such as "movement," "breathing," "reproduction," and "death" to decide whether things are alive. Thus, some believe fire, clouds, and the sun are alive, but others think plants and certain animals are nonliving. … High-school and college students also mainly use obvious criteria (e.g., "movement," "growth") to distinguish between "living" and "nonliving" and rarely mention structural criteria ("cells") or biochemical characteristics ("DNA"). This activity specifically addresses this misconception.

Activity

1. Ask students if they think there is life elsewhere in the universe. Probe to see why students think there is or is not life. (Answers will vary). Explain that there is a field of science called Astrobiology (write the word on the board and explain what it means – the study of the origin, evolution, distribution, and future of life in the universe; refer to the Science Background for more information about astrobiology). Explain that astrobiologists are studying ways to look for life on other planets and moons, and in order to do that they need to understand the nature of life.

2. Write the following question on the board: How do you know if something is alive? Encourage an open brainstorming session, steering the discussion to include the idea that living things: consist of one or more cells; grow and develop; respond to changes in the environment; consume raw materials (eat) for energy; produce waste products; and reproduce. Write these characteristics of living things on the board. Note that these characteristics define scientifically observable behaviors of living things. Do not exclude other responses from the list, but rather go over them one by one, recognizing that it isn't just one characteristic that defines something as alive. For example, movement alone doesn't render something as living; an empty bottle can roll down the hill. Point out that it is difficult to define something as alive by just one or two of these characteristics. For example, a wildfire appears to grow and produce waste products (CO_2) as it consumes raw materials (trees and brush) and appears to respond to its environment (changing direction with the wind), but fire is not considered a living thing. To define something as alive, one must look at many characteristics collectively.

3. Ask students under what conditions living organisms exist. Students will likely respond with the conditions at the surface of the Earth – a moderate, narrow temperature range, oxygen to breathe, liquid water to drink, sunlight, moderate atmospheric pressures like those on the surface of the Earth, and a steady source of food. List these responses on the board, noting that these conditions define where one would find the life forms with which students are probably most familiar, such as trees, humans, and elephants. When finished, title the list "Conditions for Familiar Life."

4. Probe to see if students think life is possible in more extreme conditions, such as very cold places (e.g., the interior of Antarctica), very hot places (hot springs), in rocks deep underground (no sunlight, no air), or at the bottom of the sea (high pressures, no sunlight). Have students justify their responses.

5. Distribute the handout "Examples of Earthly Extremophiles." Explain that scientists have indeed discovered and begun to study life (mostly bacteria and other microorganisms) in the most extreme environments on Earth. Read aloud or have students read aloud the information on the handout. Note that the thumbnail pictures on the handout are the same images as appear on the front of the poster. Larger versions of the thumbnail pictures can be downloaded from http://nai.arc.nasa.gov/poster.

   Discuss as a class how the life forms mentioned in each extreme environment meet the characteristics of life discussed earlier – What would they eat? What would they use for energy? Do they reproduce? Refer to the science background on the back of the poster for more information to support this discussion, if needed. Make a second list on the board titled "Conditions for Extreme Life." With student input based on the handout, list descriptions of the conditions in which extremophiles live (for example, very hot and very cold temperatures, very little rain, no sunlight, "crushing" pressures, no air/oxygen, broad range of pH, presence of liquid water, etc.).

6. On the board, draw a circle around each list, making sure they overlap in the middle as in a Venn diagram. Referring to the two lists, ask students what the extremophiles' conditions have in common with each other and with other "familiar" life, like us (*all require liquid water*). Explain that all life on Earth requires liquid water at some point during its lifetime. *Please refer to the science background narrative (on the back of the poster or downloadable) for information to support this discussion.* Use the space created by the overlapping circles in the Venn diagram to illustrate that both familiar and extreme life require liquid water. If desired, have students create the Venn diagram on the back of the handouts, comparing and contrasting the conditions that support familiar and extreme life on Earth.

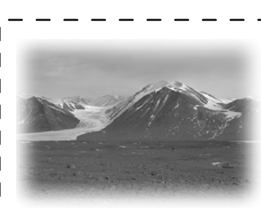
   Point out that for extremophiles, the conditions that we consider "extreme" are "normal" or "familiar." To them, the conditions at the surface of the Earth – moderate temperatures, sea level air pressure, and oxygen in the air – are extreme and deadly. "Extreme" is a relative term. If desired, collect students' Venn Diagrams for assessment at the end of class.

7. Explain that the existence of extremophiles has changed the way scientists think about life and where it can exist. They have had to modify their theories and expand their view of what types of environments are habitable based on the new information presented by the existence of extremophiles. Discuss as a class how studying extremophiles influences the search for life on other planets. Steer the discussion to include the following points: 1) understanding how life survives in Earthly extreme environments can help scientists better understand how life might survive on other planets and moons; 2) conditions that we think of as "extreme" on Earth may be similar to what is "normal" elsewhere in the solar system; 3) knowing that life can exist in more extreme conditions than previously thought means there are more extraterrestrial environments that could potentially support life; and 4) researchers can use Earthly extreme environments to test equipment and techniques they might someday use to search for life on another planet or moon.

   Point out that the discovery and study of extremophiles helped spur the development of the field of astrobiology, illustrating the need for an interdisciplinary approach to the questions: what is life and where is it.

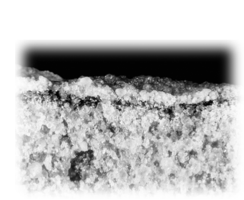
8. Have students write a paragraph, either in class or as homework, addressing the question: Why is the study of extremophiles on Earth important to the search for life on other planets? *Students should mention the four points listed above.*

STUDENT HANDOUT

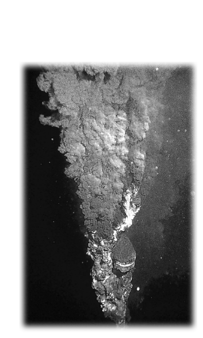


McMurdo Dry Valleys in Antarctica

Grand Prismatic Springs in Yellowstone NP



Layer of microbial life inside rock



Hydrothermal Vent "black smoker"

Acidic river Rio Tinto in Spain

Examples of Earthly Extremophiles

Cold – The McMurdo Dry Valleys in Antarctica are some of the coldest, driest deserts on Earth, with average annual temperatures of –20°C (-4°F) and less than 10 centimeters (4 inches) of precipitation a year. Scientists have found bacteria in liquid water pockets embedded about six feet deep in solid ice. Some of these bacteria use chemical nutrients from particles of dirt in the ice and use energy from sunlight for photosynthesis.

Hot – Large concentrations of microbes thrive in Yellowstone National Park's Grand Prismatic Springs, a boiling hot spring, with water temperatures up to 90°C (188°F). Other hot springs in Yellowstone are extremely acidic, yet are home to many different kinds of bacteria and microbes. Many of these microbes use chemical nutrients in the hot springs and energy from sunlight for photosynthesis.

Deep underground – Scientists have found bacteria living 1.5 kilometers (1 mile) deep in basalt rock underneath the state of Washington. The bacteria, which live in complete darkness, survive in small holes in the rock that fill with water from underground aquifers. The bacteria generate energy from chemicals formed from reactions between the groundwater and the rock.

Bottom of the sea – Scientists have found abundant life clustered around hydrothermal vents on the ocean floor, including bacteria, mussels, clams, shrimp with no eyes, and giant tube worms that can reach ten feet in length. Water pouring out of the vents in the complete darkness thousands of feet under the surface of the sea can reach temperatures of 400°C (750°F). The high pressures (thousands of tons per square inch) keep the water from boiling. Bacteria use chemicals in the vent's water, primarily hydrogen sulfide, as their energy source instead of sunlight. Other creatures survive by eating the bacteria or each other. The tubeworms have no mouths and no stomachs. They depend on bacteria in their guts for their nutrition. Hemoglobin in the worm's red tips grabs hydrogen sulfide from the water around the vent and transports it to the bacteria living inside the worm. Using hydrogen sulfide as a source of energy, the bacteria, in turn, convert carbon dioxide dissolved in the water into carbon compounds that nourish the worm.

High Acidity – The water in the Rio Tinto river in southwestern Spain is very acidic, a result of chemical reactions between the water and iron and sulfur minerals in the ground. The river has a deep red color, like wine, because of iron dissolved in the water. Microbes, living in the water use chemical reactions with iron and sulfur minerals to generate energy. Products from these metabolic reactions contribute to the low pH in the environment. Many algae and fungi also live in the acidic waters.